STRENGTH OF LIGHTWEIGHT AGGREGATE FOAMED CONCRETE EXPOSED TO ELEVATED TEMPERATURES

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ABSTRACT

This paper reported an investigation on six mixes of Lightweight Aggregate Concrete (LWAC) were produced to study the effect of elevated temperature (200 to 700 ˚C) on the residual mechanical properties. The first three mixes were considered as reference mixes consisting of cement, Porcelanite as coarse aggregate, and fine Porcelanite as a partial replacement and total replacement of sand. Two percent of foam agent by weight of water was added to produce Lightweight Aggregate Foamed Concrete (LWAFC). The results of testing showed that the high elevated temperatures resistance of foamed concrete is better in terms of the proportional loss in strength than normal concrete. Also, the mechanical properties of LWAFC containing 50% and 100% of fine Porcelanite aggregate are less affected by high temperature than the sanded LWAFC.

Keywords: lightweight concrete, foam concrete, elevated temperatures, thermal conductivity, porcelanite.

INTRODUCTION

Studies have been conducted widely on a large number of natural lightweight aggregates to manufacture lightweight concrete (LWC) [1-4]. Use of natural lightweight aggregate instead of ordinary aggregate can reduce the cost of such concretes. There are deferent types of natural lightweight aggregate such as perlite, pumice, Porcelanite, volcanic scoria, diatomite, etc.

The cellular structure of a LWA makes it inherently insulating, and this factor is responsible for the high thermal insulation of the LWAC. Also, this type of LWC has generally a lower thermal expansion than Normal Weight Concrete (NWC), therefore, it is more stable at elevated temperature than many dense aggregate concrete. This property, combined with the better thermal insulation, produce the inherent fire resistance of LWAC [5-7].

The heat exposure may be found in some industrial installations where concrete is used in places exposed to sustained elevated temperatures ranging from (100-1000) °C as in foundation for blast furnaces and coke batteries, furnaces wall and dampers, industrial chimneys, flues, kilns and nuclear- reactors [3].

Since concrete is a composition of different materials, the behaviour of concrete under elevated temperatures depends on its constituents. The aggregate type and structure of cement paste has a great effect on thermal conductivity of concrete. The highly porous microstructure of lightweight aggregate (LWA) gives it low density and better insulation and that makes the concrete made with LWA exhibit lower thermal conductivity than that of normal weight concrete (NWC). Therefore, Lightweight Aggregate Foamed Concrete (LWAFC) provides more effective fire protection than other types of concrete as it is less liable to spalling and has a higher thermal insulation [2].

Therefore, many studies have been carried out to investigate the properties of Lightweight Concrete (LWC) exposed to elevated temperatures by using various Lightweight aggregate (LWA). There are also papers dealing with the effect of high temperatures on chemical and mechanical properties of LWC [1-4], however, there are few papers dealing with the effect of high temperatures on chemical and mechanical properties of Foamed Concrete (FC) [9]. So, this investigation is suggested to study the properties of foamed concrete, and try to improve their properties by using local and low cost materials. In this work, compressive and density are to be measured. The analytical study involves thermal conductivity analysis of the LWAFC.

Abbreviations	
LWAC	Lightweight Aggregate Concrete
LWAFC	Lightweight Aggregate Foamed Concrete
NWC OPC ASTM LOI IQS	Normal Weight Concrete Ordinary Portland Cement American Society for Testing and Materials Loss On Ignition Iraqi Standards

RESEARCH SIGNIFICANCE

This paper focuses on the use of foamed concrete with Porcelanite as a coarse aggregate and as a partial and total percentage replacement of fine aggregate. The primary scope is to study the effect of high elevated temperatures on properties of LWAFC.

Experimental investigation

The effect of various test parameters on the properties of LWAC and LWAFC. All mixes were exposed to different temperature levels and the period of exposure at the maximum temperature was two hours.

The investigation was based on using locally manufactured cement Type I (OPC) produced by Al Kubaisa Cement Factory, whose chemical and physical properties are shown in Table-1 and Porcelanite crushed

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stone obtained from the north of Al-Rutba Town in Al-Anbar Governorate - Iraq. Table-2 lists some important physical and chemical properties for coarse and fine Porcelanite aggregate. Foaming agent type EUCO was used in this study to produce LWAFC with 2% foaming agent by weight of water [9]. Table-3 indicates the technical description of the foaming agent.

The coarse aggregate used was 10 mm in all mixes. The fine aggregate used Porcelanite as partial and total replacement with local natural sand whose fineness modulus 2.61. Its gradation lies in zone 3 and the grading test results conform to Iraqi Specification No.45/1984 as shown in Figures 1 and 2 which show grading of fine and coarse aggregate used in this investigation. Potable water of Al-Risafa, Baghdad, was used throughout this investigation for mixing and curing.

Test parameters

The test parameters investigated were:

- Porcelanite as fine aggregate replacement, partial and total replacement;
- Level of exposure temperatures, at an age of 60 days, the specimens were heated in an electric furnace, four maximum temperature levels were selected (200, 300, 400 and 700°C) the period of exposure at the maximum temperature was two hours.

MIXTURE PROPORTIONS AND DETAILS

Investigation was carried out in three different series and mix proportioning was calculated according to ACI 211-98 [10]. An extensive series of tests were conducted to develop suitable LWAC, and LWAFC reinforced with fiber, are classified into classified into two series:

- Series I - MSP, MSPP, MPP: mixtures details are presented in Table-4
- Series II - MSPF, MSPPF, MPPF: mixtures details

Table-1. Chemical and physical properties of cement.

Chemical properties		
Oxides composition	**Content %**	**Limit of Iraqi specification No. 5/1984**
Lime, CaO	62.5	-
Silica, SiO_2	21	-
Alumina, Al_2O_3	4.9	-
Iron oxide, Fe_2O_3	3.08	-
Magnesia, MgO	1.5	5 % Max.
Sulfate, SO_3	2.3	2.8 % Max.
Loss on Ignition, (L.O.I)	1.5	4 % Max.
Insoluble material	1.1	1.5 % Max.
Lime Saturation Factor, (L.S.F)	0.937	(0.66-1.02)
Main compounds (Bogue's equation)		
C_3S	50.96	-
C_2S	21.77	-
C_3A	7.77	-
C_4AF	9.36	-
Physical properties		
Specific surface area (Blaine method), (m^2/kg)	304	230 m^2/kg lower limit
Setting time (vicate apparatus) Initial setting, hrs. : min Final setting, hrs. : min	2:05 3:60	Not less than 45 min Not more than 10 hrs
Compressive strength (MPa) For 3-day For 7-day	20.4 28.2	Not less than 15 MPa Not less than 23 MPa
Expansion by Autoclave method	0.23 %	Not more than 0.8 %

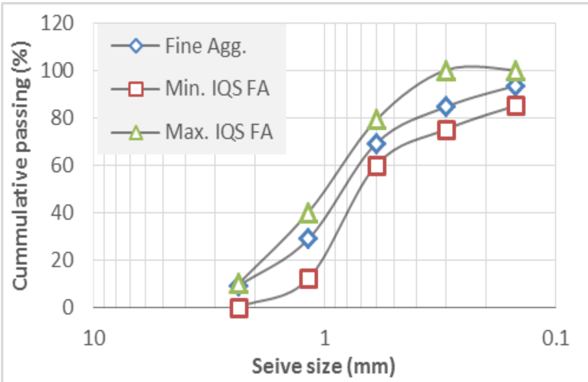

Figure-1. Particle size distribution of fine.

Concrete Mixing, Test Specimens, Curing, Condition, and Testing Details

The mixing sequence was as follows: coarse aggregate and fine aggregate, added in the mixer and mixing continued for 1minute, then the required quantity of dry cement was added, and mixing continued for 3 minutes at which a good homogenous mix was produced.

Two thirds of the required quantity water were then added to the dry materials, and the remaining water and the required quantity of foaming agent were added to the machine to make foam which was then added to the mix [9].

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Table-2. Chemical and physical properties of fine and coarse Porcelanite aggregate.

Physical properties			
Property	**Coarse aggregate**	**Fine aggregate**	**Specification**
Specific gravity	1.55	1.68	ASTM C127-04
Absorption, %	39	42	ASTM C127-04
Dry loose unit weight, kg/m³	600	740	ASTM 29/C29M/02
Dry rodded unit weight, kg/m³	685	860	ASTM 29/C29M/02
Aggregate crushing value, %	16		BS 812-part 110-1990
Chemical properties			
Oxides	% by Weight		
SiO_2	69.86		
CaO	10.57		
MgO	6.90		
SO_3	0.30		
Al_2O_3	4.78		
Fe_2O_3	2.09		
TiO_2	0.18		
L.O.I	4.25		
Total	98.97		

Table-3. Physical properties of foaming agent.

Appearance	**Liquid**
Color	Transparent
Specific Gravity	1.01
Chloride Content	Nil
Compatibility with Cement	All Types of Portland Cement
Shelf Life	Up to 2 Year
Surface Tension	41.9N/cm^2

The slump of fresh concrete mixtures was determined as per ASTM C143. Sixty days compressive were determined by crushed 100mm cubs as per B.S. 1881: part 120:1983, and flexural strength was determined by crushed (400× 200 ×50) mm flags as per IQS No.1107, 1988 Type C [11]. Three specimens were tested for each test and mean values were reported. Two specimens (200× 100× 50) mm were cast for each concrete mixtures to check the thermal conductivity as per B.S. 874:1973 [12].

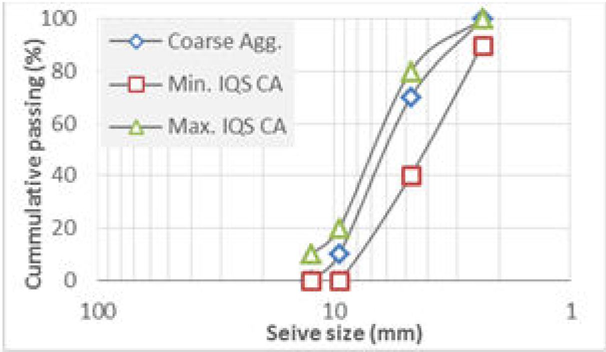

Figure-2. Particle size distribution of fine aggregate.

Heating procedure

For all exposures, the specimens were slowly heated and cooled to allow the maximum exposure temperature to reach the centre of the specimens during heating and the rate of heating was such that it should not exceed 2 °C/min to avoid steep thermal gradient [1, 13].

RESULTS AND DISCUSSIONS

Fresh properties

Effect of foaming agent- Table 4 shows that the values of fresh properties (slump) of LWAC varied from (120-160) mm. For LWAFC, these values were in the range (242-248) mm. This indicated that Series II of lower w/c (0.4) had larger slump compared to Series II. It is also observed that the addition of foaming agent increased the workability due to the fact that cohesion is improved by the use of foaming agent these observations were consistent with those reported by [4,9].

Influence of high elevated temperatures on LWAC and LWAFC

Loss of weight

All series exhibited smaller loss in weight with respect to exposure temperature are plotted in Figures 3 and 4. The decrease in weight was not more than 2% at 200 ºC and 7% at 300 ºC, for all mixes. This is due to the removal of the capillary and adsorbed water from the cement paste. On the other hand, it has become obvious that there is an increase in the loss of weight at a temperature above 300 ˚C, and reduction of the weight is ranging from a minimum of about 17 % to a maximum of about 41 % at 700 ˚C. This is due to the further dehydration of the cement paste as a result of the decomposition of calcium hydroxide.

It has also been noticed that in Series I, sanded-LWAC specimens (MSP, and MSPP) showed a larger reduction in their weight compared to MPP specimens containing fine Porcelanite aggregate as a total replacement of natural sand. The results show that the MPP mixes are more thermal stable than the other mixes and the thermal stability of the concrete depends largely on the thermal stability of the aggregate.

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Table-4. Mixture composition of all experiment series, kg/m^3.

Mixture ID*	Fine Aggregate		Coarse Porcelanite	w/c	Water	Foaming agent	Slump (mm)
	Sand	Porcelanite					
MSP	540	-	787	0.4	160	-	120
MSPP	270	153	787	0.43	172	-	155
MPP	-	313	787	0.45	180	-	160
MSPF	540	-	787	0.4	160	3.2	242
MSPPF	270	153	787	0.42	168	3.36	245
MPPF	-	313	787	0.45	180	3.6	248

* All mixes content cement = 400 kg/m^3
** Aggregates in SSD condition, water quantities were adjusted before mixing

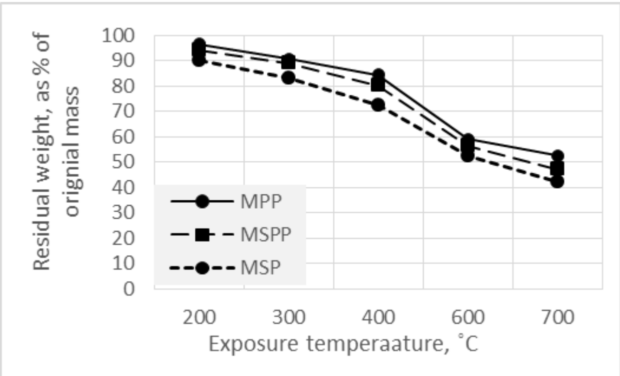

Figure-2. Residual weight as percentage of original weight of LWAC.

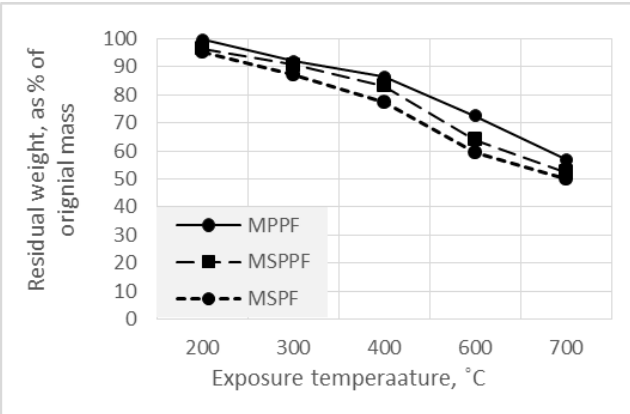

Figure-3. Residual weight as percentage of original weight of LWAFC.

COMPRESSIVE STRENGTH

The residual compressive strength of Series I, and II decreases with the increase of temperature degree Figures 5 and 6. The range of properties of Series I and II concrete presented in Table-5. Residual compressive strength at 200 ˚C for Series I is approximately (70, 83, and 86) % of MSP, MPPS, and MPP respectively. Residual compressive strength at 300 ˚C for Series I is approximately (62, 69, 80) % of MSP, MPPS, and MPP respectively. At 400 ˚C the residual strength is (38, 44, and 50) % for MSP, MPPS, and MPP respectively. At 600 ˚C the residual strength is approximately (23, 34, and 41) % for MSP, MPPS, and MPP respectively. Residual compressive strength at 700 ˚C for Series I is approximately (11, 20, and 23) % for MSP, MPPS, and MPP respectively. Residual strength of MPP is higher compared to MSP when subjected at different temperatures. The rate of loss of strength is significantly at 700 ˚C compared to the others, especially for MSP. The residual strength at 600 ˚C is equivalent to half the residual strength at 300 ˚C. At high temperature, the dehydration of cement paste results in its gradual disintegration. Because the paste tends to shrink and aggregate expands at high temperatures of above 600 ˚C, the bond between the aggregate and the paste is weakened resulting a great reduction in strength as confirmed in test results [15, 16]. The deterioration of strength at elevated temperatures for such concretes can be attributed to the coursing of the pore structure and the increase in pore diameter [15, 16, and 17].

The test results indicated that each temperature range for Series II is plotted in Figure-6. Residual compressive strength at 200 ˚C for Series II is approximately (80, 87, and 91) % of MSPF, MPPSF, and MPPF respectively. Residual compressive strength at 300˚C for Series II is approximately (69, 75, 85) % of MSPF, MPPSF, and MPPF respectively. At 400 ˚C the residual strength is (61, 63, and 69) % of MSPF, MPPSF, and MPPF respectively. At 600 ˚C the residual strength is approximately (47,49, and 50) % of MSPF, MPPSF, and MPPF respectively. Residual compressive strength at 700 ˚C for Series II is approximately (40, 44, and 47) % of MSPF, MPPSF, and MPPF respectively.

Generally, the strength loss in Series II is lower compared to Series I when the temperature is varied from 200 to 700 ˚C. For instance, at 700˚C, the residual strength (40, 44, and 47) % of MSPF, MPPSF, and MPPF respectively which are considered higher compared to Series I. This is an indication of better performance of LWAFC in retaining the strength at elevated temperature as compared with LWAC. This can be attributed to the less dense pore structure of Series II (compared to Series I) due to the presence of comparatively porous cement paste and lightweight aggregate (Porcelanite).

At 700 ˚C, Series I, and Series II specimens experience considerable cracks as well as spalling. The color of specimens also changes to pink. The specimens undergo surface features when exposed to 600 ˚C also showed color changes as well as some edge cracks but not as severe as those exposed to 700 ˚C as shown in Figure-7. Series II should exhibit more resistance to high elevated temperatures than Series I due to lesser tendency to spall and loss of lesser proportion of its original strength with the rise in temperature [18].

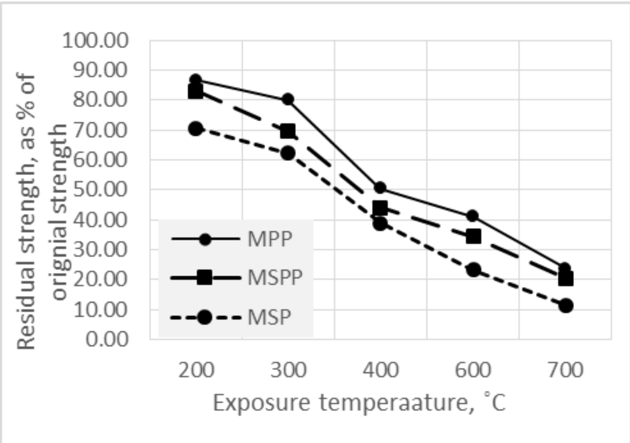

Figure-5. Residual strength as percentage of original strength of LWAC.

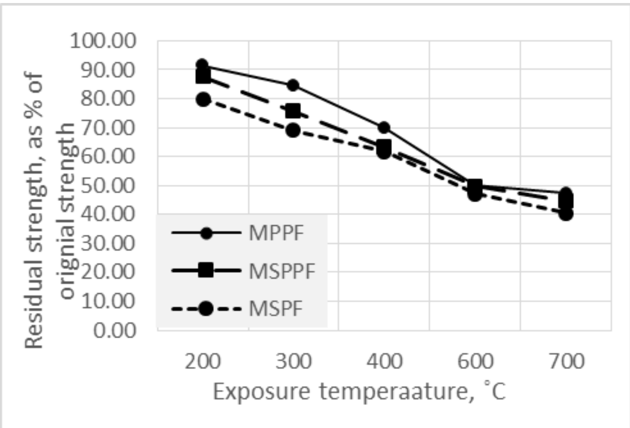

Figure-6. Residual strength as percentage of original strength for LWAFC.

Figure-7. Concrete specimens after 2 hrs. of high elevated temperatures.

THERMAL CONDUCTIVITY

The variations in the thermal conductivity of all series specimens with respect to exposing temperature are plotted in Figure-8. The coefficient of thermal conductivity will decrease when the air-filled pores increase, air being a very poor conductor of heat, thus the results showed that the coefficient of thermal conductivity of the Series II is lower compared with Series I. Also, the thermal test has a good indicator of the behavior of LWAFC under high elevated temperatures. Generally, the results showed that the Series II mixes have more thermal stability compare to Series I. The thermal conductivity dropped sharply for sanded- LWAFC (MSP) between 300 and 700 ˚C, approximately (35.2, 40.1, 40.3, 61.5, and 73.9) % at (200, 300, 400, 600, and 700) ˚C respectively, while the same mixes with the foaming agent undergo a slight drop approximately (27.9, 31.6, 35.7, 53.5, and 64.2) % at (200, 300, 400, 600, and 700) ˚C respectively. The thermal stability of the concrete depends largely on the thermal stability of the aggregate (i.e., thermal strain depends on aggregate used) [13]. This is firstly due to the cellular nature of Porcelanite aggregate and secondly due to the mineral composition of this type of aggregate which consists of approximately 65% Opal mineral type Opal-CT which is considered as amorphous siliceous minerals and has low thermal conductivity compared with crystalline silica [19]. The results also show that the addition of foaming agent gives better thermal insulation to LWAC mixes at 25 ˚C. Simply, the high elevated temperatures resistance requirement is based on thermal insulation.

CONCLUSIONS

The following conclusions can be drawn from this study:

- The addition of foaming agent by 2% was beneficial in improving the workability of LWAC. The slump values of LWAFC between 242 to 284 mm showed satisfactory workability with no segregation or excessive bleeding specially for MPPF mixture.

- The compressive strength and density decrease with the increase of the Porcelanite replacement with sand. The proportional loss in strength between normal concrete LWAFC containing 50% (MSPPF) and 100% fine Porcelanite aggregate (MPPF) showed a little loss in mechanical properties compared with the sanded-LWAFC (MSPF).

- The behavior of Series I mixture under compressive strength was more sensitive to elevated temperatures than that of Series II.
- The residual compressive strength of series II specimens was more than series I especially when exposed to high temperatures, the residual strength is (69, 50, and 47) % of MPPF at 400 ˚C, 600 ˚C, and 700˚C respectively.
- MSP specimens have a minimum residual strength comparison with the others, especially at high elevated temperatures, equal to (38, 23, and 11) % at 400 ˚C, 600 ˚C, and 700 ˚C respectively.

Table-5. Summary of mechanical properties.

Mixture ID*	Density, kg/m^3						Compressive strength, MPa					
	Temperatures, ˚C						Temperatures, ˚C					
	25	200	300	400	600	700	25	200	300	400	600	700
MSP	1500	1431	1345	1265	884	786	19.4	16.8	15.5	10	8	5
MSPP	1457	1372	1297	1169	823	685	18.5	15.4	13	8	6.4	4
MPP	1280	1154	1063	924	672	538	15.8	11.2	10	6	3.6	2
MSPF	1390	1385	1277	1201	1007	790	13	12	11	9	6.5	6
MSPPF	1351	1302	1225	1126	864	709	10	8.7	7.5	6.3	4.9	4.5
MPPF	1210	1159	1053	934	720	606	9.4	7.5	6.5	5.8	4.4	3.7

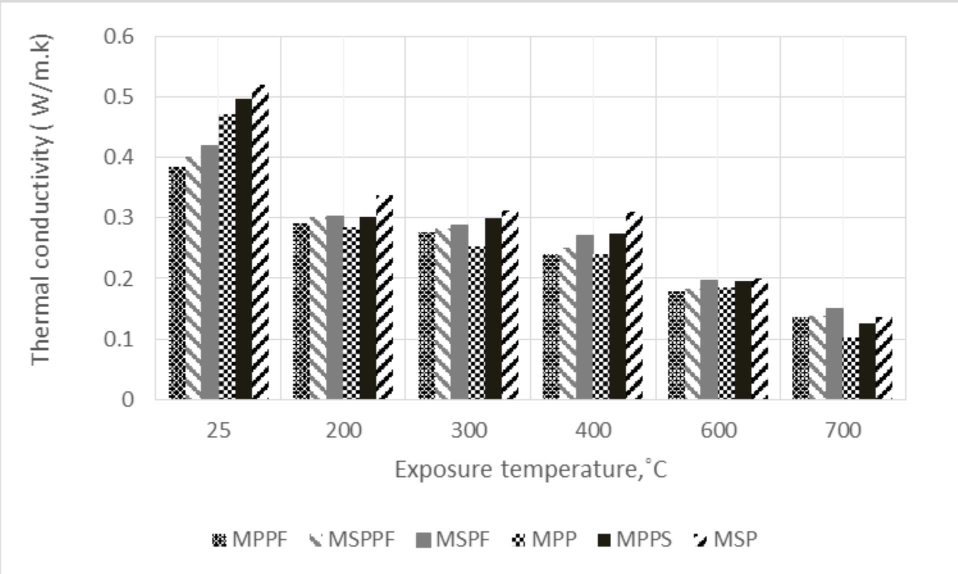

Figure-8. Thermal conductivity for series I and II exposed to different temperatures.

ACKNOWLEDGEMENTS

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